The results reported in this document have been made in one location, Chabot Park.(Figure 5.1) The location was selected for several reasons. First, the received signals were of approximately equal signal strength and the location was line-of-sight to both transmitters. The assumption that the signals from each transmitter propagated along a line-of-sight path to the receive vehicle, was based on the measured relative delay. Measurements consistently recorded 10 microseconds, which correlates well with the respective distances from the receive location. The Roundtop site is approximately 2 miles further away than the Hayward site.

Second, the received signals were well above the receiver noise threshold. Typical received levels were -80dBm. Since the two transmitters are not phase coherent, there will be occasions, assuming equal signal strengths, when the signals will cancel each other at the receiver. This condition will not persist since the two carrier frequencies will be different even with the high quality reference oscillators used in the transmitter paging units. Only small deviations from an anti-phase condition are required to yield adequate signals, providing both signals are well above the noise threshold of the receiver. The destructive and constructive behavior can be observed as 'beating' of the resultant received signal. The two transmitters were set to be on the same frequency but in practice were within 5 Hz of each other from the start to finish of the test sessions.

Third, the location was remote so there was little disturbance from temporal fading - approximately $\pm$ 1dB signal level changes were observed during the tests for each transmitter. The receiver was stationary throughout the duration of the measurements. For these tests, the signal levels of the two transmitters were set equal as received by the receive vehicle. In practice, the relative power levels, as measured by the receive vehicle, were maintained within a $\pm$ 2dB margin.

6.0 Test Method

Before we began any tests, we turned all equipment be turned on and allowed it to warm-up for at least 20 minutes. In the case of the PURC 5000 transmitters, two hours were required for the reference oscillators to stabilize.

Since all the measurements of power levels and delay are relative, no exhaustive calibration of the integrated equipment was necessary at the beginning of each test session. However, individual instruments, such as the receiver, have been calibrated with NBS traceability.

The steps in doing the tests were as follows :

- Accurately measure the frequency of each transmitter. Ideally, to make the measurements independent of periodic bit errors due to phase cancellation (as mentioned above), the transmitters should be frequency aligned (assuming that the receive vehicle is not located at a site where the two signals cancel). In reality, even with the high quality reference oscillators used on paging transmitters, this is impossible over long time intervals.

- Confirm that the signal strengths of each transmitter are equal as received by the received vehicle. In practice, achieving equal signal strengths at the receiver was a combination of adjusting the height of the receive antenna and adjusting the output power of one of the transmitters. The final signal levels measured at the receiver was -80dBm. Before the adjustments the difference in signal levels was approximately 5dB.

- Set up the differential delay of the two transmitters. Delays can be inserted at either transmitter.

- Confirm that the GPS receivers at each transmitter site and in the receive vehicle have a 'fix'. Generally, for the sites selected that had clear views of the horizon, the receivers were able to maintain a 'fix' on the satellites for most of the day. Mornings tended to be the worst time.

- Before any measurements were done with both transmitters on, it was confirmed that no bit errors were received at all data rates from each transmitter on its own.

- Measure the relative delay of the two transmitted signals with respect to the receive site. Selecting the Mark Space data sequence, one of the transmit sites was de-keyed and the demodulated signal of the other stored on an oscilloscope. The other transmit signal was then measured while the former was turned off. The oscilloscope, in both instances, was triggered by the GPS 1pps. Observing both waveforms on the oscilloscope, the delay was measured as the difference between the two signals at the zero crossing points.(Figure 6.1) We observed in doing the measurements that opening the low-pass filter to the 6.4 kbaud setting allowed the best compromise between a sharp pulse transition and minimizing the ringing on the trailing edge of the pulse.

- Selecting each data rate in turn, measure the BER for a duration of 2 minutes. For each selection, the corresponding audio low-pass filter needs to be selected at the receiver as well as the appropriate IF filter; 230kHz for 12.8kbaud and 15kHz for the remaining data rates. In addition, the appropriate splatter filter needs to be selected at the transmitter.

- Before proceeding to do the same tests of the previous paragraph with a different delay setting, it was thought prudent to check the signal levels of each transmitter.

A similar test routine can be followed to measure the effect of relative power levels of the transmitters as seen by the receiver for a given relative delay. In this case, the relative power levels are adjusted and the relative delay kept constant. Further tests will be done to ascertain the relative power difference required to achieve an acceptable BER for a given delay. In reality, the power difference will also be dependent on the type of demodulator and detection scheme.

7.0 Results To Date

We demonstrated that two paging transmitters can be synchronized with less than 1 microsecond of relative delay.(Figure 4.3.1) The small relative delay has been achieved using GPS receivers at each transmitter site in combination with a synchronization logic unit. The inherent relative delay of the transmitters themselves is less than 100 nanoseconds.

By also including a GPS receiver in the mobile receive vehicle, the relative delay of the two received signals could be measured. As a result of the accuracy of GPS, the relative delay was measured to within an accuracy of 1 microsecond (1000 feet). The software at the transmit sites allowed the relative delay of one transmitter to be arbitrarily changed with respect to the other. This facility allowed measurements to be made at any one location for all relative delays. An observation of the measurements for the site chosen was that there was no discernable variation (<< 1 usec) of the relative delay.

The measurements clearly show that operating at 1.2 kbaud provides a robust simulcast paging system. BER measurements show very little degradation at 1.2kbaud irrespective of relative delay and relative signal strength. Obviously, extending the delays beyond 160 microseconds would degrade the performance. However, in reality, delays in excess of this number where the received signal levels are of similar amplitude, within 10dB, will rarely occur. Only a few such cases have been reported in such locations as Switzerland and Salt Lake city where unique geographical circumstances have contributed.[2].

In general, the results in Figure 6.3 show an expected trend. Higher data rates are degraded more (increased BER) for a given relative delay between the two received signals. This is also true when delay is considered as a percentage of bit rate, except in the case of 12.8kbaud. For example, for 20% relative bit delay, the BERs are :

	1.2 kbaud	2.4 kbaud	3.2 kbaud	6.4 kbaud	12.8 kbaud
t (usecs)	166.7	83.3	62.5	31.3	15.6
BER	1.0E-5	2.0E-4	5.0E-3	3.0E-2	1.0E-2

Table I - BER for 20% relative bit delay

It can be noticed that the BERs for 6.4 and 12.8kbaud closely follow each other up to 20 microseconds of relative delay. In fact, the lower data rate has a higher BER at zero relative delay. A possible explanation is that the phasing of the respective RF signals and the distortion at the higher data rate of 6.4kbaud (25kHz bandwidth) in combination, are more predominant as a source of bit errors than the relative delay between the two signals. This may also explain the higher BER of 6.4kbaud over that of 12.8kbaud shown in Table I above.

The effects of increased delay have a significant effect for data rates of 2.4 kbaud and higher. As the relative delay becomes a substantial part of a bit duration, the signal waveform deteriorates dramatically and BER increases. Even with no relative delay between received signals, all data rates except 1.2 kbaud show a residual BER. This is believed to be due to the phasing of the RF signals as one signal periodically processes past the other subject to the condition of equal signal strength. 1.2 kbaud is not effected since the dropout is an insignificant duration of the bit period. We noticed that the errors tended to occur in bursts. For the measured delays, 2.4 and 3.2 kbaud do not significantly degrade from the residual BER, whereas for 6.4 and 12.8 kbaud, the relative delays become significant so that at 80 and 40 microseconds respectively, the signals cannot be received (BER = 10^{-1}). For BER values of less than 1 in 100, it was found that the BER tester would lose synchronization every so often. These results are therefore taken over shorter durations than the results which were taken over a duration of two minutes. For longer delays at all data rates, the bit errors are predominantly due to the two signals constructively and destructively interacting due to the relative delays. Figure 6.2 shows the demodulated output of the receiver illustrating the effect of relative delay and anti-phasing of the signals.

Measurements in Figure 6.3 show the effect of baud rate under a worst case condition of equal signal strength. We noticed after additional measurements that the BER improves with an increase in the relative signal strength of the two signals. In the worst cases, where the data rate in relation to the delay produces a BER that is barely measurable, approximately 10dB of relative signal level is required to make the detection process independent of relative delay. At this point, the demodulator has 'captured' the stronger signal, a well known phenomenon with FM demodulators. The figure of 10dB is a function of the receiving equipment. Also, initial measurements indicate that when the relative delay is a low percentage of the bit period, the relative signal difference is less than 10dB.

The results described above are likely to apply to the case of three or more transmitters, since in many cases, only two transmitters will be the more dominant in defining the simulcast environment in a local area.

8.0 Conclusions

Field tests at different data rates and bandwidths have been successfully performed using a mobile receive vehicle and two transmitters operating in a simulcast mode. The measurements were performed in the San Francisco area at 930.5 MHz.

It has been demonstrated that synchronization of the two transmitters can be achieved to within one microsecond using GPS.

Tests have been performed under a worst case condition, namely equal received signal levels of the two transmitted signals. Results to date show, as expected, that more bit errors occur for the higher baud rates. More specifically, 1.2 kbaud is not effected, in terms of bit errors, for relative delays below 160 microseconds whereas, in contrast, 12.8 kbaud cannot be received for delays in excess of 40 microseconds. At 6.4 kbaud, the combined signals cannot be received for delays in excess of 80 microseconds. All data rates, except 1.2 kbaud, show a residual BER for no relative delay between the two received signals. For the data rates of 2.4 and 3.2 kbaud, the BER does not significantly degrade from the residual BER. All BER measurements are raw BERs with no coding correction.

Initial measurements suggest that, at most, 10 dB of relative signal level is required between two received signals before BER becomes independent of relative delay. 10 dB is required for the extreme cases where the relative delay of the two received signals is a significant duration of a bit period, up to 50% and BERs are high.

9.0 Further Work

In the near future, further measurements are planned to add to and confirm the present results. Additionally, another receive site is planned for measurements in a suburban location. These measurements will also include varying the offset in transmit carrier frequencies. Further investigation of the effect of relative signal strength on BER will also be made as a function of data rate and relative delay.

To complete this phase of testing, the empirical results will be used in conjunction with prediction plots to identify simulcast problem areas and their respective size as a function of data rate. Having identified these coverage areas, average delays will be measured for the areas which can then be directly related to BER for a given data rate using the field measurements described above. Fade margins for the type of environment will also be included. This part of the test will combine the measurements of the field trials as well as employing prediction tools.

Based on the conclusions of these tests, an investigation into different coding and modulation schemes will be made.

10.0 References

[1] 'Paging Simulcast Test Plan', submitted to the FCC in November, 1991 as part of the amendment application.

[2] 'A Physical Mobile Radio Channel', W.R. Braun & U.Dersch of ABB, Switzerland.

Figure 2.1
Simulcast Paging System Test

PacTel Paging
Experimental License

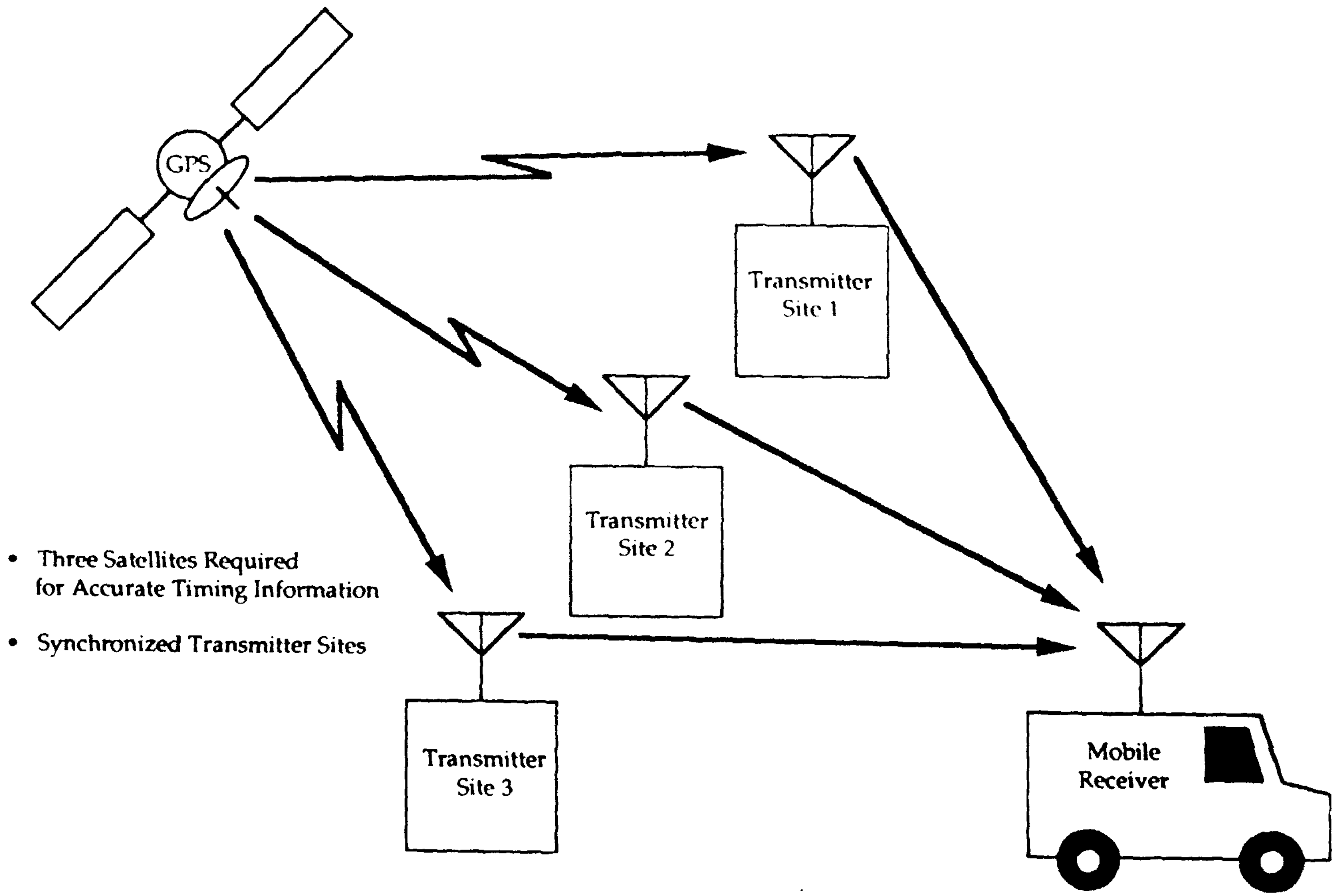
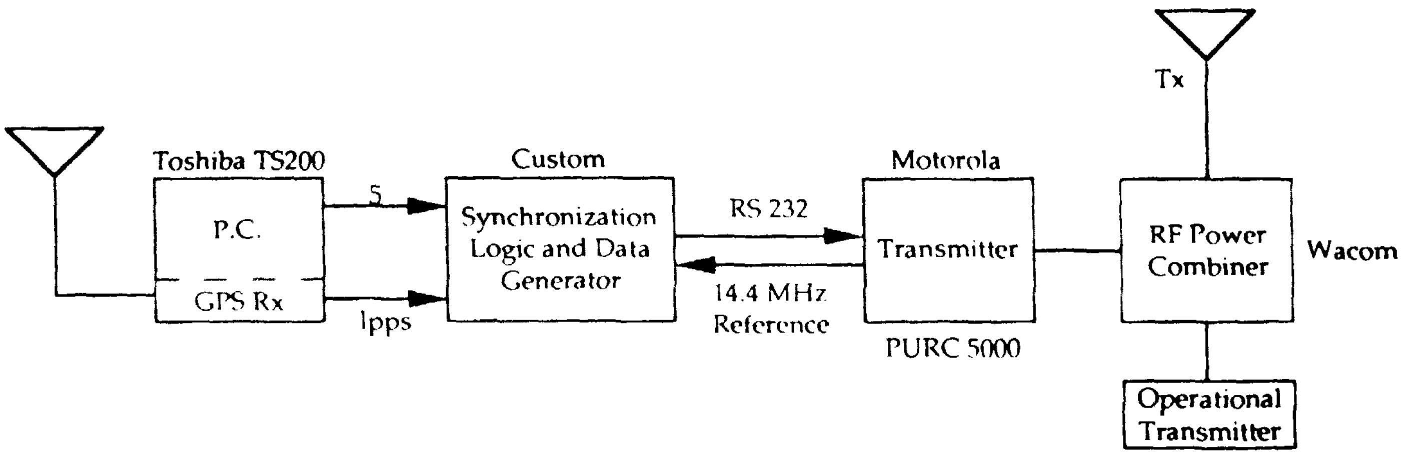


Figure 4.1.1
Block Diagram of Transmitter



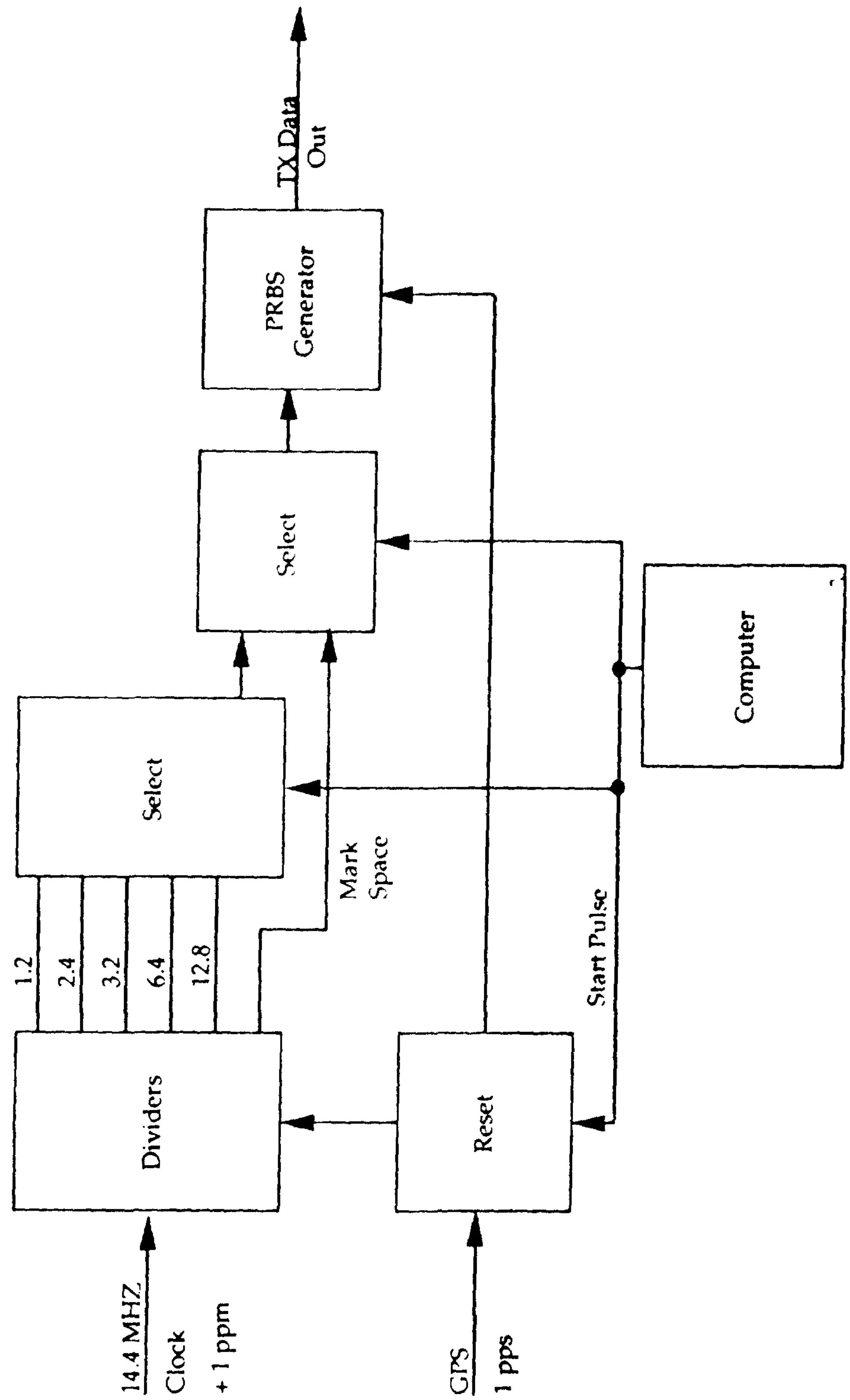


Figure 4.1.2
Block Diagram of Synchronization Logic Unit

a)

b)

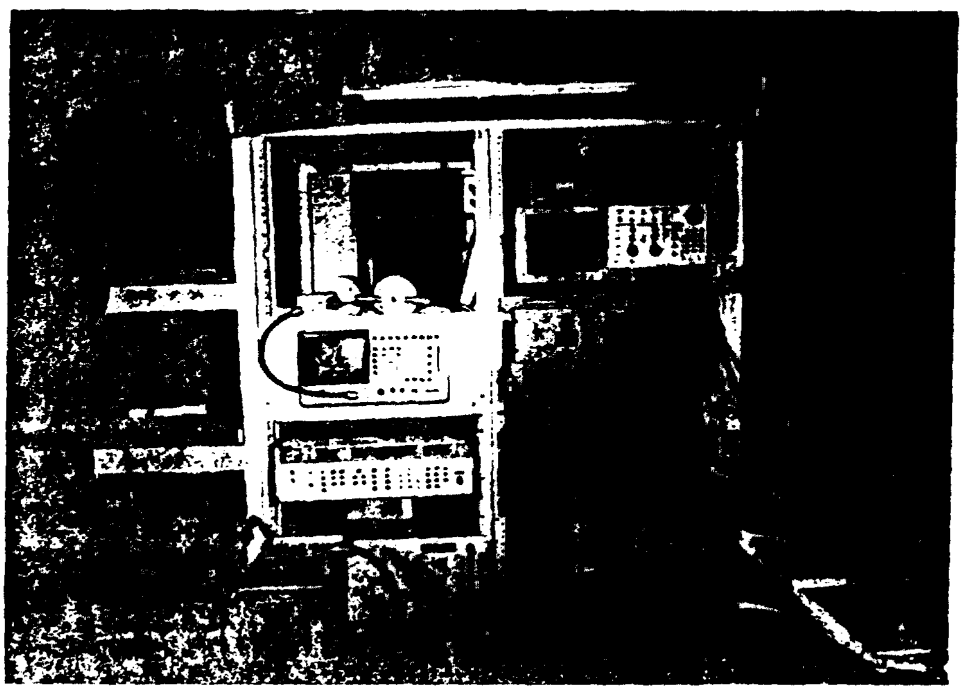
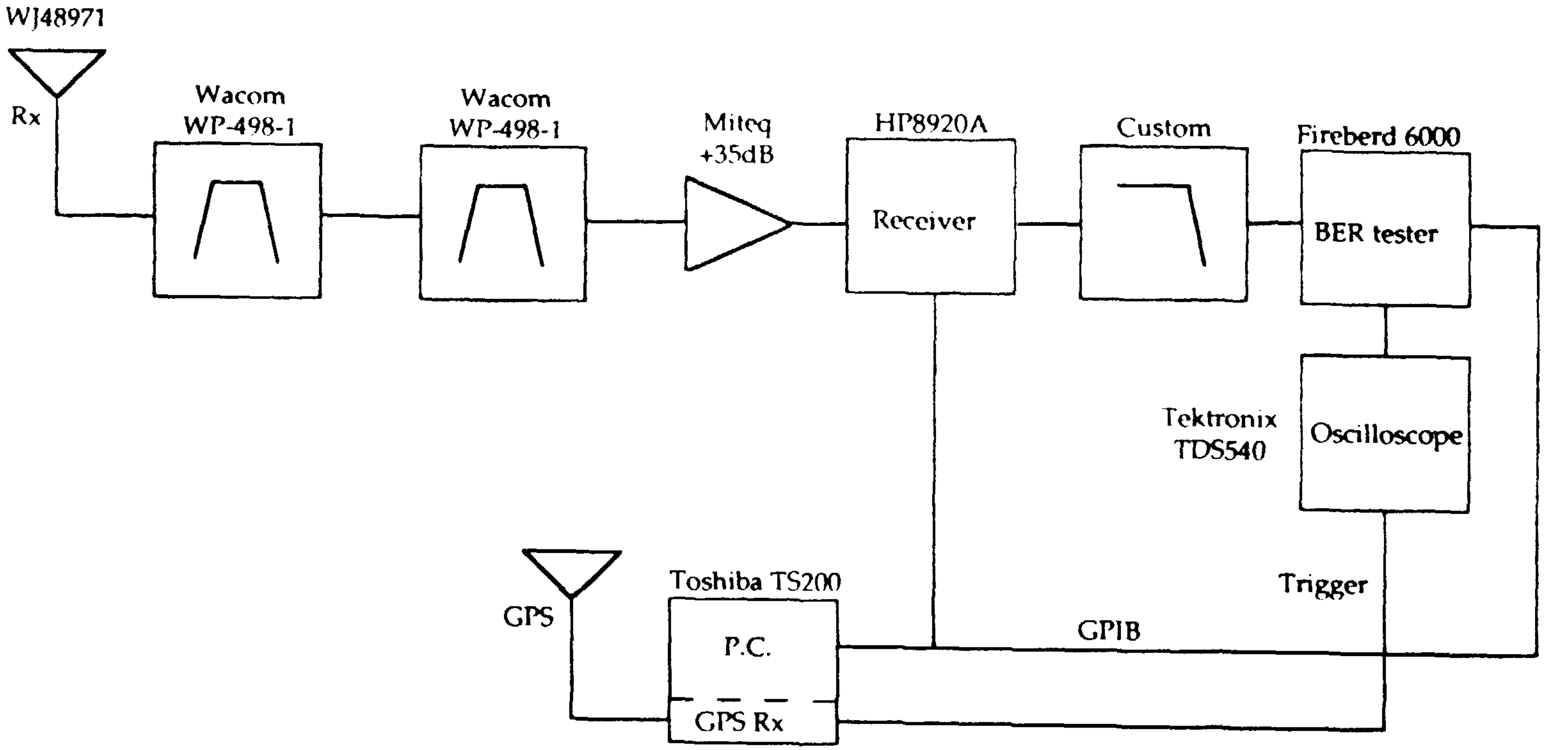
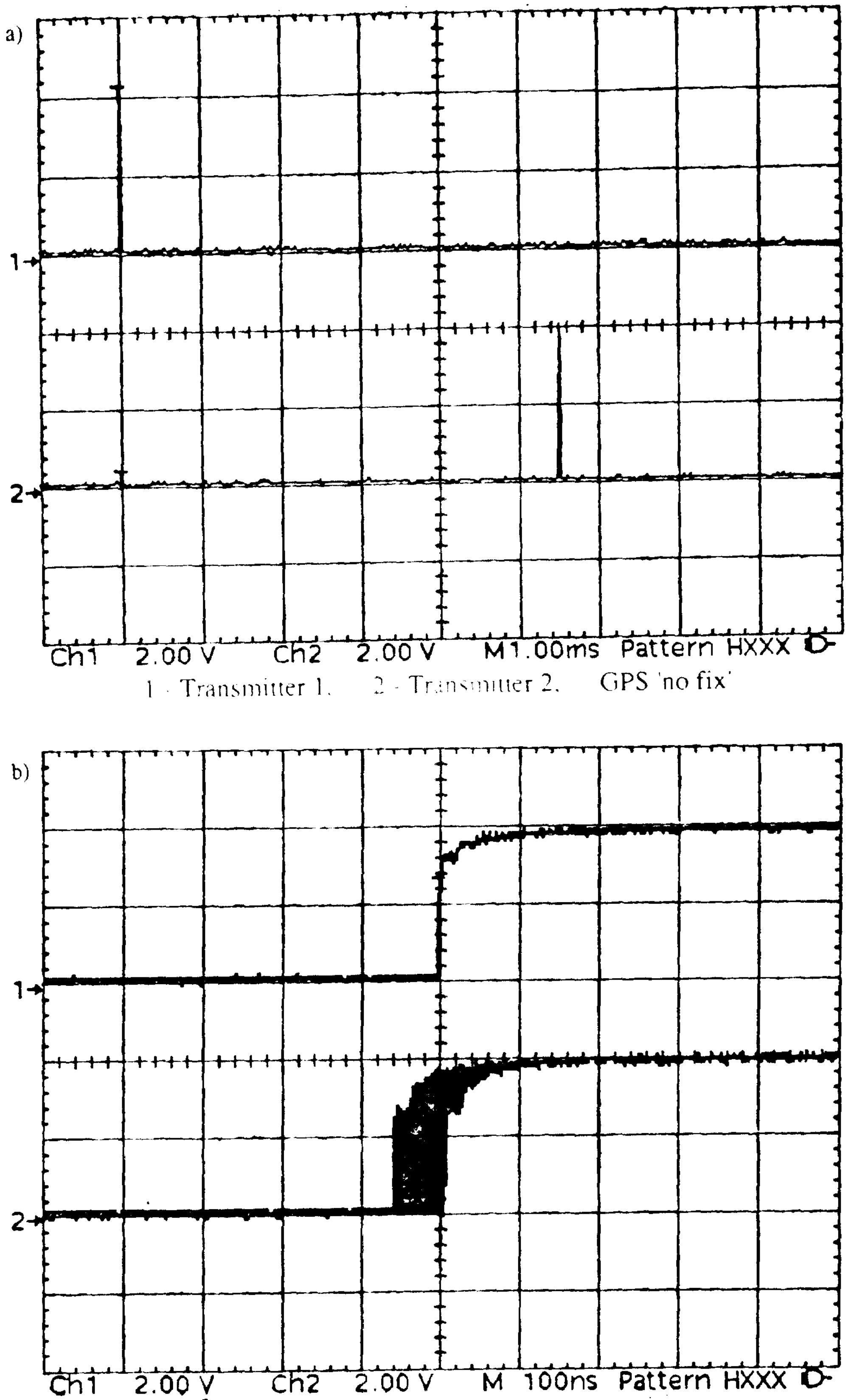


Figure 4.2.1

Figure 4.2.2
Block Diagram of Receiver

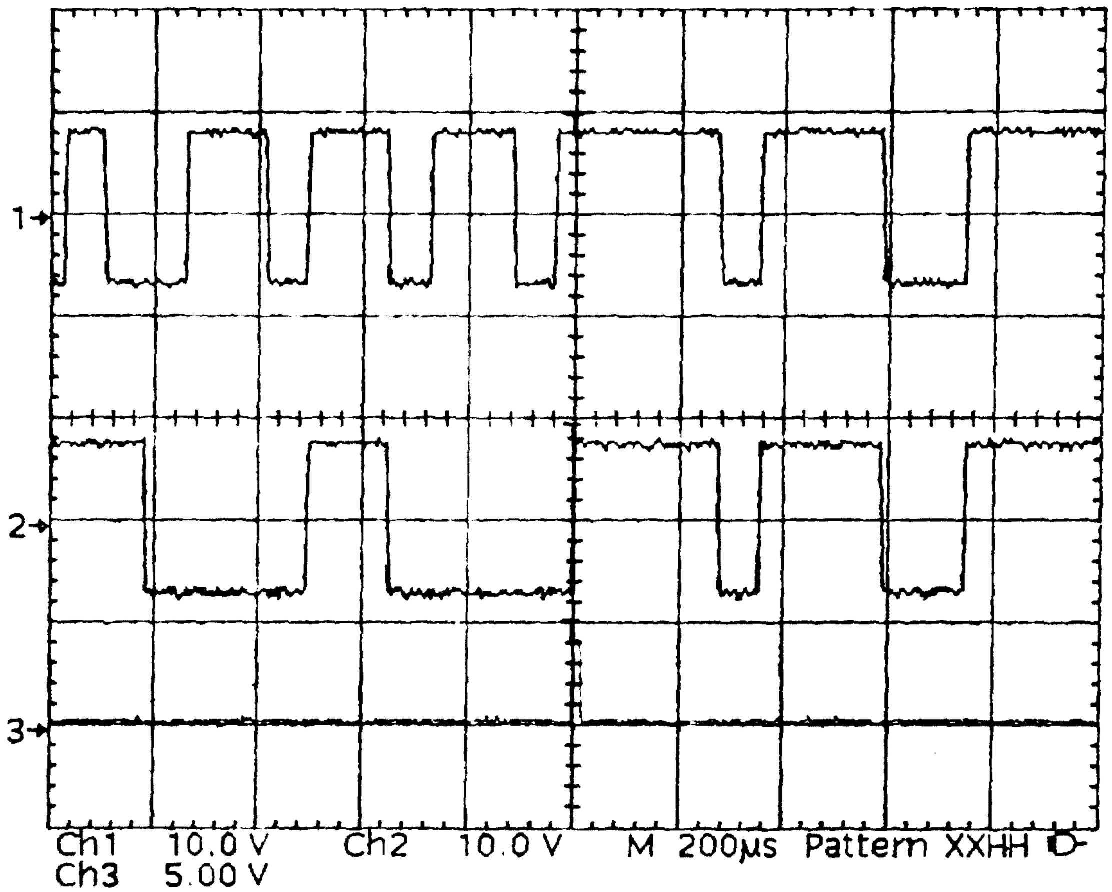




1 - Transmitter 1. 2 - Transmitter 2. GPS 'no fix'

1 - Transmitter 1. 2 - Transmitter 2. GPS 'fix'

Figure 4.3.1
GPS 1pps Synchronization
(General Figure Description)



1 - Transmitter 1, 2 - Transmitter 2, 3 - GPS 1pps.

Figure 4.3.2
Synchronization of Data

Figure 5.1
Best Server Coverage

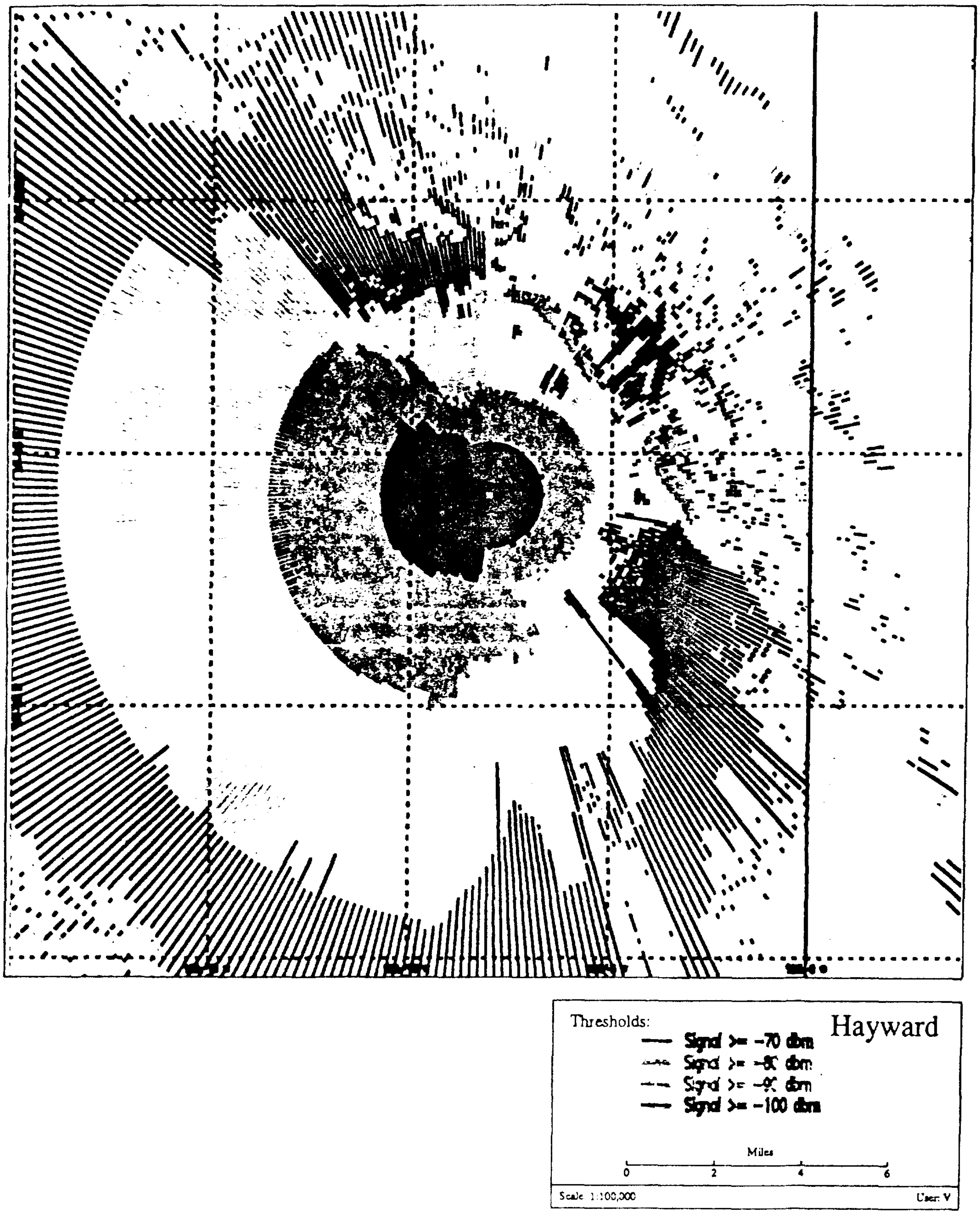


Figure 5.2
Hayward Signal Coverage

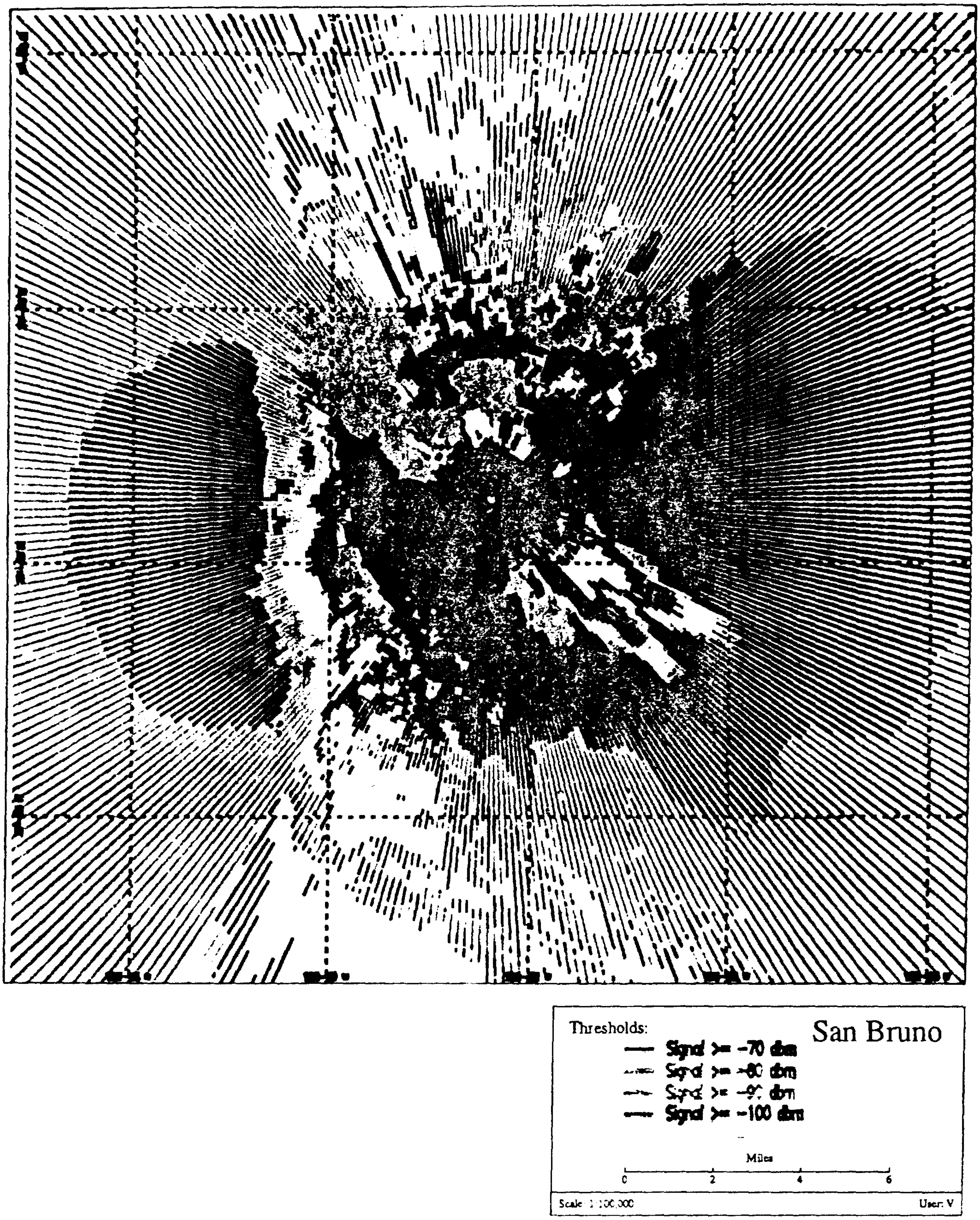


Figure 5.4
San Bruno Signal Coverage

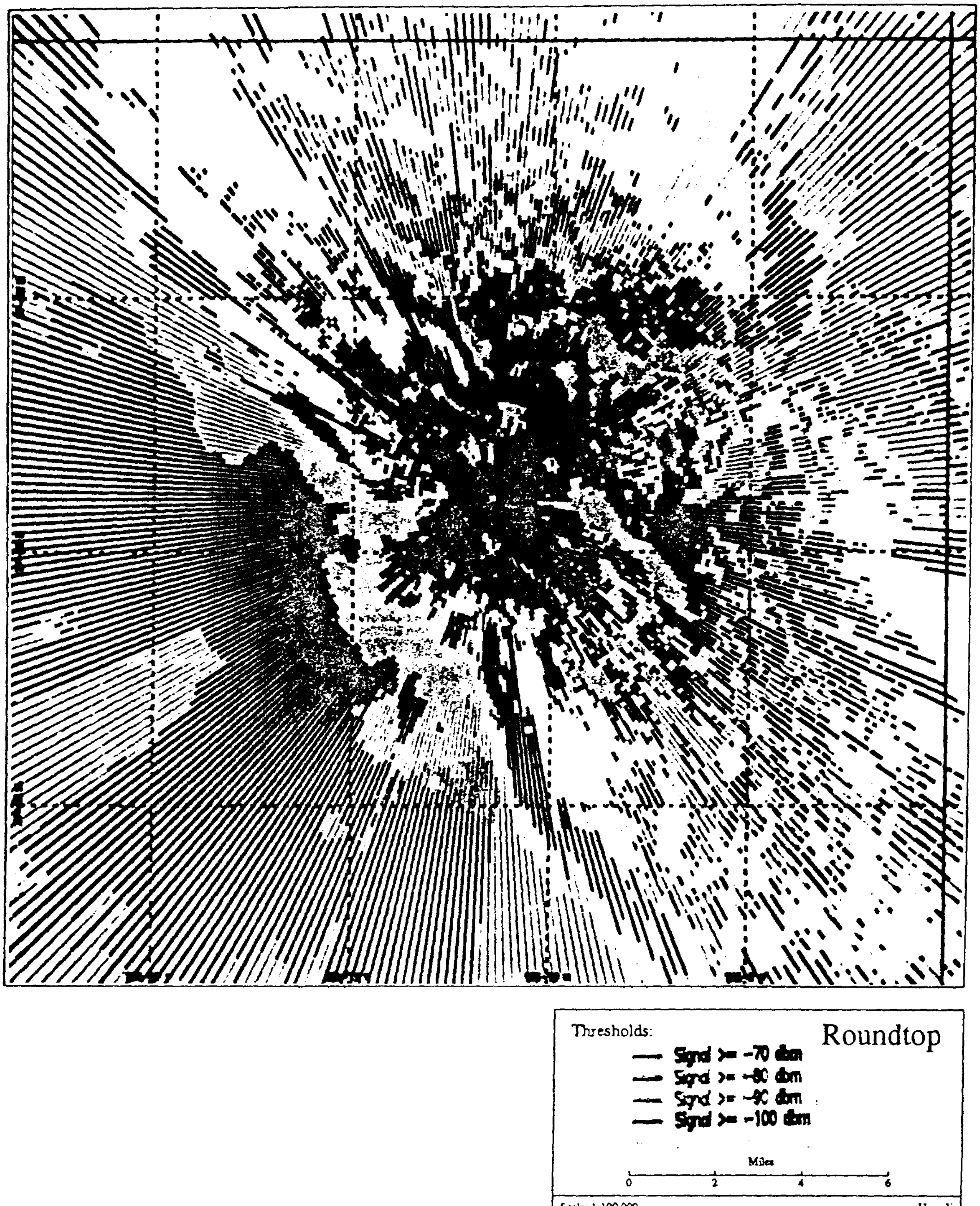


Figure 5.3
Roundtop Signal Coverage

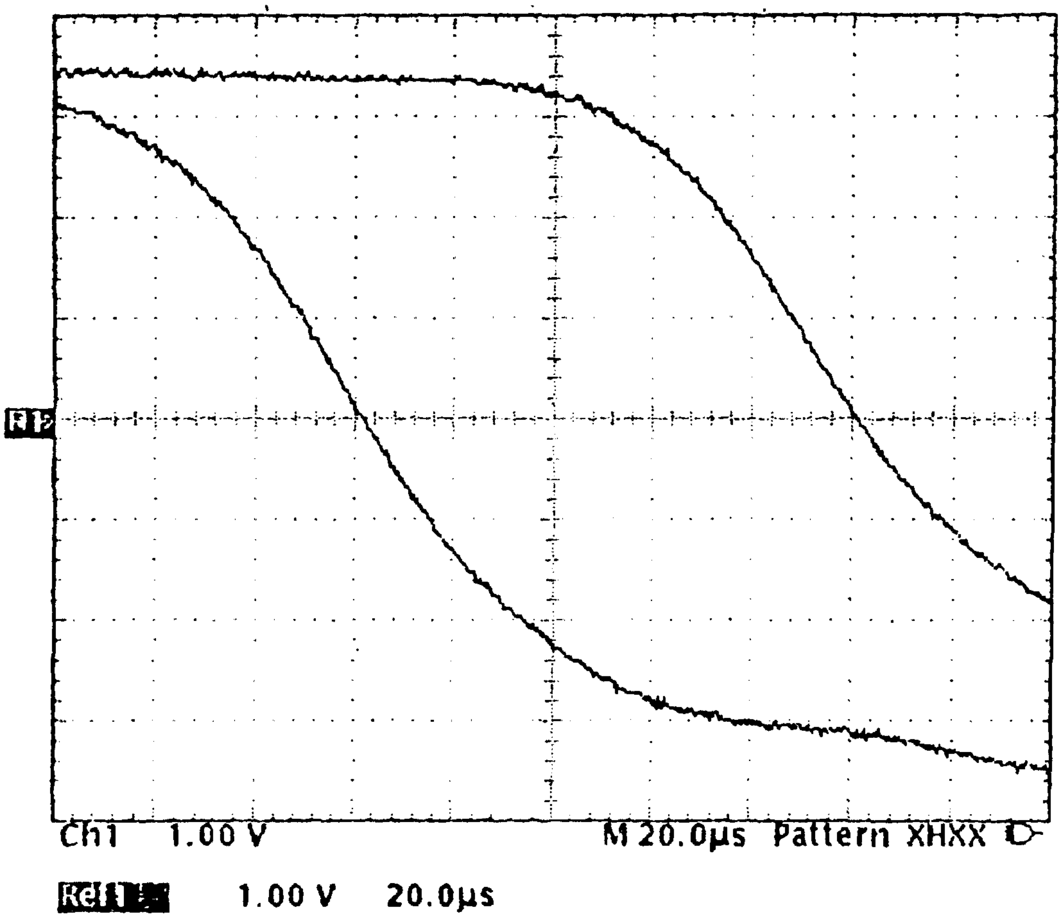
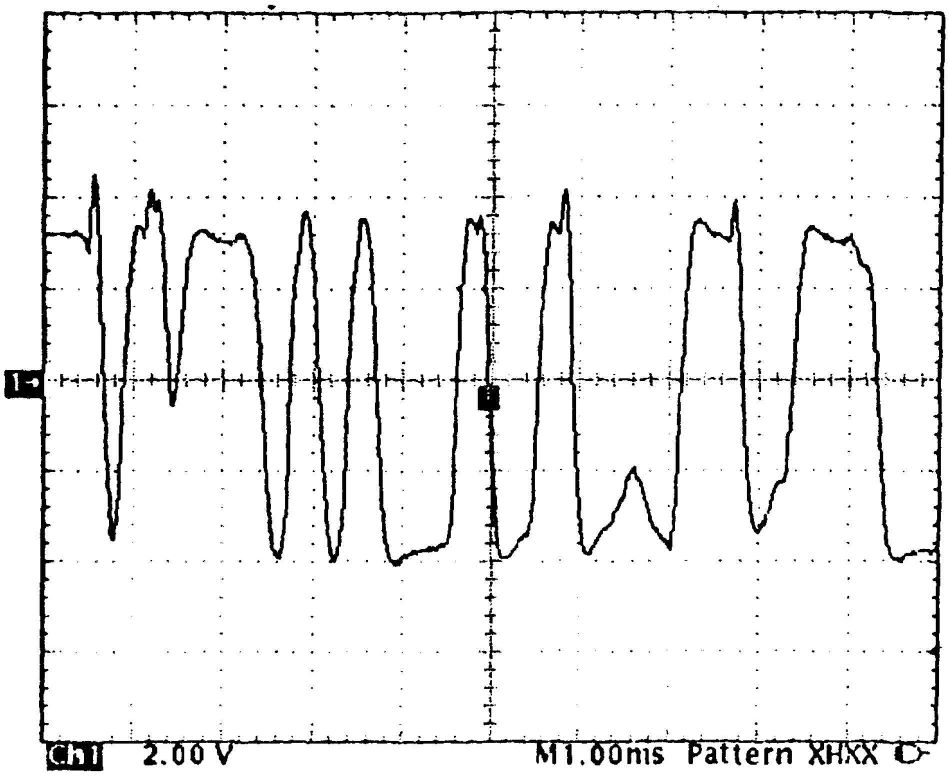
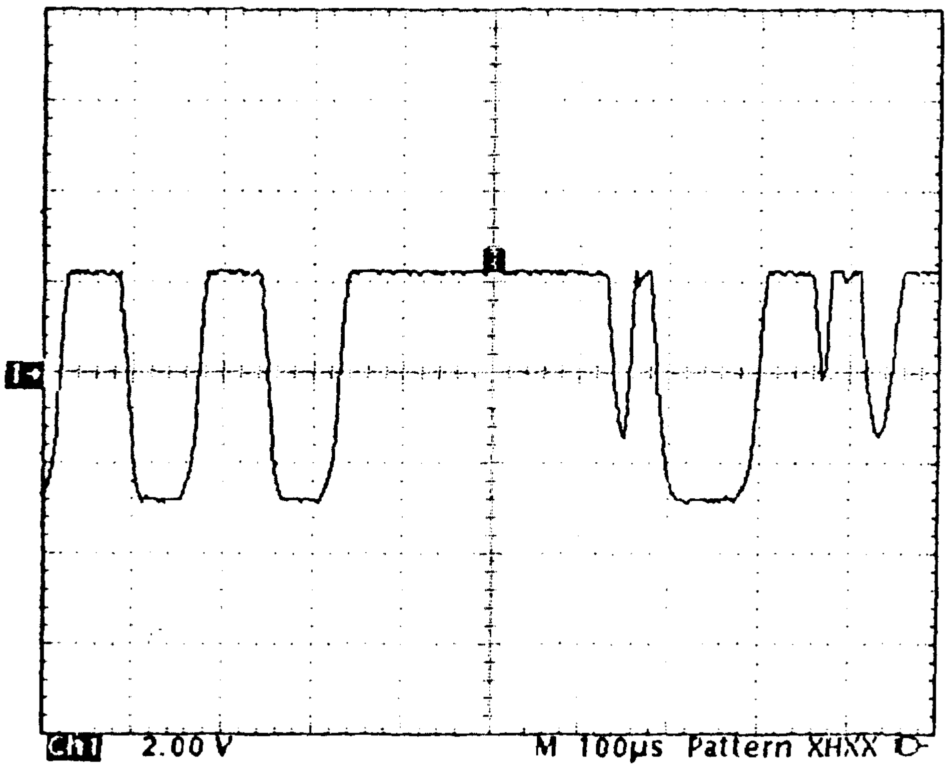


Figure 6.1
Example of Delay Measurement



Data Rate = 3.2 kbaud, BER = 1.6×10^{-3}, Delay = 20 μ seconds



Data Rate = 12.8 kbaud, BER = 2.5×10^{-2}, Delay = 20 μ seconds

Figure 6.2
Examples of Data Measurement

ATTACHMENT 4

Advanced Architecture Paging Experimental License

Presentation to the FCC

May 27,1992

PacTel Paging
Telesis Technologies Laboratory

Background

- On February 20, 1991, an Experimental License was granted to Pacific Telesis to conduct RF propagation and system tests in five cities throughout the US. This license was subsequently transferred to Telesis Technologies Laboratory.
- On July 29, 1991, Telesis notified the commission of details of its experimental program for Advanced Architecture Paging (AAP).
- On August 2, 1991 PacTel Paging filed a Petition for Rulemaking proposing the allocation of a portion of the 930-931 MHz band for AAP.
- PacTel Paging, under the auspices of TTL, are presently continuing experimental tests with regard to AAP. These tests are being done under a special temporary authority issued December 27, 1991.

Definitions and Objectives

Definition: Advanced Architecture Paging

- AAP is an unformatted paging service which, unlike the present paging formats (POCSAG, GOLAY), does not impose internal formatting limitations, thus offering enhanced messaging capabilities, e.g. longer alphanumeric messages, E-mail, enhanced character sets

Objectives:

- In order to maintain or increase capacity for the enhanced messaging capabilities, AAP will require higher data rates.
    - Assess upper limit of present day paging:
        - Simulcast Environment
        - FSK Modulation
    - Investigate alternative modulation and coding schemes, bandwidths and data rates

Problem

Simulcast Environment

- ❑ Relative Delays
  - Propagation
  - Hardware
- ❑ Relative signal strengths of signals
- ❑ Phasing of frequency references

Arrangement of Simulcast Transmitters